
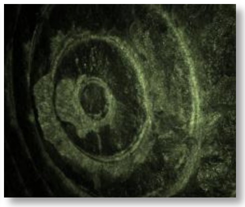


Microtunneling in Rock: Fact or Fiction?

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This paper presents Bradshaw Construction's perspective on whether microtunneling in hard rock is fact or fiction. It is based on Bradshaw's fifty years of tunneling experience as well as nearly a decade of experience microtunneling through full and mixed face metamorphic and sedimentary rock formations throughout the Eastern US. Many in the industry are simply unaware of the developments in microtunneling equipment, materials, and construction techniques that now allow the benefits of microtunneling in most rock conditions.

The fact is that rock microtunneling has been going on since the 1990s. It was and still is very successfully performed in sedimentary rock formations with all sizes of MTBMs. In Bradshaw's experience, sedimentary rock behaves much like dense soils and often produces record microtunnel production rates. Only very hard abrasive sandstone presents a challenge for microtunneling in sedimentary rock. In those conditions, cutting tool wear can limit drive length or necessitate face access to replace them.

In the late 1990s and early 2000s, numerous contractors attempted to microtunnel igneous and metamorphic rock formations with mostly poor results. The rock was hard and abrasive, causing rapid wear and damage to the cutting tools before most drives could be completed. The microtunnel tunnel boring machines (MTBMs) at that time did not allow face access to change the cutting tools during the drive. The contractors who attempted these microtunnels often did not have tunnel engineering and construction experiences with conventional TBMs. They did not understand both the limitations of the microtunneling equipment they were using or what the geotechnical information was telling them they needed to cut the rock. The result was a series of valiant attempts to achieve the same results that microtunneling had in soft ground but through difficult rock formations.





In the early 2000s Herrenknecht introduced its T series of MTBMs that have "face access". This was revolutionary because for the first time the contractor could enter the MTBM cutterhead to change the cutting tools and continue the drive instead of back pulling the MTBM to the jacking pit or digging a rescue shaft or tunnel to replace the worn or damaged cutting tools. And while face access interventions can be risky in mixed face conditions under the water table, they have been safely performed and are absolutely critical to the "economic" success of microtunneling in full face hard abrasive rock. These T-series MTBMs are also heavier and have greater torque than comparably sized soft ground MTBMs allowing them to cut harder rock formations. However, to achieve face access, they are no smaller than 59.25" OD. Even at this size the face access door is only 18" ID and the work space in the cutterhead chamber so small that a large person cannot fit into it. Changing cutting tools is difficult and rather expensive, but at least possible.

MTBMs smaller than 59.25" do not have face access, therefore their ability to mine hard abrasive rock remains more fiction than fact today. Their small size and small cutting tools simply cannot put enough pressure on hard rock to cut it efficiently, if at all. The small amount of metal on the cutting tools can also wear away quickly. This is especially true for the critical perimeter gage disc cutters. It has been known to happen in as little as 20' of tunneling, making it very risky to attempt to mine such formations with a MTBM that doesn't have face access.

Worse yet, even with face access and the increase in torque and weight, microtunnel boring machines are still "MICRO". They use small cutting tools to cut the rock. The larger MTBMs with face access typically use 11" disc cutters capable of only 17,000+/- pounds of thrust. Compare that to a 10' diameter conventional TBM using 17" disc cutters capable of 70,000 pounds of thrust and you begin to understand the serious physical limitations of MTBMs and where the fiction of hard rock microtunneling begins. We do not believe, however, that those limitations can be specified by a simple measurement like an upper limit on unconfined compressive strength (UCS). Too many other factors are involved such as rock fracturing, hardness, abrasiveness, mineralogy, MTBM size, power, thrust, torque, cutterhead design, etc. The decision of when to use microtunneling in hard rock should be analyzed using conventional rock TBM models with geologic and MTBM parameters. And while slurry microtunneling is limited in its ability to mine massive hard rock formations, we have found that the slurry provides distinct advantages over conventional TBMs when mining in decomposed, weathered, and mixed face conditions. This is significant because most microtunnels are designed at shallow depths where such conditions are typically encountered.

Bradshaw started rock microtunneling in 2004 using a Herrenknecht face access MTBM.

By that time we had forty years of drill and blast hand tunneling experience and over ten years of hard rock TBM experience in similar rock formations as well as thirteen years of soft ground microtunneling experience. Since then, Bradshaw has completed thirty drives totaling over 14,000’ in predominantly hard abrasive metamorphic rock. Only six of the drives have been in the less challenging sedimentary rock. The microtunnels have ranged in diameter from 36” to 77” OD and in length up to 1,000’. The rock has ranged in unconfined compressive strength (UCS) from 500 to 43,500 psi and abrasivity from Cerchar 1.0 to 5.5. The 43,500 psi rock contributed to the decision to stop one of the drives and install a drill and blast MTBM rescue tunnel. This was the only rock microtunnel drive we did not complete. We completed five other drives totaling 3,200’ on that project through full and mixed faced rock of similar hardness by increasing the overcut, and modifying the MTBM and jacking procedures. Nearly half of our rock microtunnel drives have required MTBM face intervention to replace cutting tools. Our current project in Raleigh, NC, which consists of 662’ of 60” & 72” FRP through full and mixed face granitic rock, has required multiple face interventions and disc cutter changes. Our other recent projects were not large enough diameter to allow face access and were completed without incident. They consisted of 330’ of 43” OD steel casing through weathered Schist in Fairfax County, VA, and 800’ of 36” OD steel casing through limestone in Miami, FL.

We believe the key to successful rock microtunneling is to understand both the geology of the project and the limitations of the microtunneling method, equipment and materials. We cannot emphasize enough the importance of a thorough geotechnical exploration and testing program for microtunneling in general, but especially for rock microtunneling. Without such information, it is nearly impossible to determine the appropriateness of the microtunneling method itself, much less the MTBM equipment, cutterhead, cutting tools, and jacking pipe for the project.

The following are Bradshaw’s recommendations for the geotechnical study:

- Type of rock by drive and within drive length
- Location of any transition zones from rock to soil creating mixed face or mixed reach drives
- Orientation & spacing of rock fractures/bedding
- Unconfined Compressive Strength (UCS) with description of structural or non-structural failure of every test
- Cerchar abrasivity Index
- RQD (%)
- Recovery (%)
- Brazilian Tensile Strength
- Point Load Test
- Punch Penetration Test
- Thin Section Petrographic Analysis including description of any mineral suturing conditions.
- Historical research into previous TBM tunnels in the area that may have encountered rock suturing or other “tough rock” mining conditions such as amphibolite or diabase.

Rock microtunneling presents unique challenges for the MTBM and jacking pipe as well as the means and methods utilized. After nearly a decade of experience, we have the following observations and recommendations:

1) MTBM Advance Rate – A simple formula for calculating rock TBM mining rates per shift is instantaneous penetration rate per revolution x cutterhead revolutions per minute x mining hours per shift. Conventional hard rock TBM cutterheads turn at 10-18 RPM while MTBM cutterheads turn at 2.5 to 5 RPM. MTBMs also have significantly lower instantaneous penetration rates due to their disc cutter's lower thrust capacity. Therefore, MTBMs mine hard rock substantially slower than any conventional TBM and this difference gets greater as the rock gets harder.

2) Cutting Gage – Perimeter gage disc cutters mine the tunnel opening. They do it by being turned nearly perpendicular to the direction of the tunnel and thus are subject to significantly greater wear from abrasion than the other disc cutters. If they wear too much, then the MTBM becomes obstructed by its own shell. The microtunnel drive must be short enough or the MTBM must allow face access to replace them in hard abrasive rock for the drive to be successful.

3) Overcut - For rock microtunneling, where settlement is rarely an issue, we recommend the overcut selection be left up to the contractor. From experience, we generally set the overcut 25% to 50% greater than in soft ground microtunneling to allow the gage cutters to wear down and not obstruct the MTBM. Debris in the overcut void can create substantial and damaging increases in friction since the rock tunnel walls do not yield like soft ground soils do. Increasing the overcut seems to minimize the impact of such debris build up. However, the overcut cannot be so large as to limit the MTBMs ability to develop articulation steering reactions.

4) Cam Locking and Pipe Wedging – Cam locking creates point loading from an object trapped in the overcut void. Wedging involves slurry cuttings passing under the MTBM cutterhead which leads to lifting then wedging the MTBM and pipe string against the roof of the tunnel. These two conditions can happen repeatedly during a rock microtunnel drive and can cause jacking loads to spike by 50% to 100%. This creates two critical problems.
    a. Telescopic Tail Can – The jacking load spikes result in surges in the pipe string that in turn causes thrust load spikes to the MTBM cutting tools unless the MTBM is isolated from the pipe string advancement by the use of a telescopic tail can (telecan). This is basically a pipe interjack station (IJS) that is directly attached to the rear of the MTBM.

The operator uses the telecan to advance the MTBM independent of the pipe string. This allows more careful control and measurement of the thrust applied to the MTBM and indirectly to the cutting tools. Surging from cam locking and wedging of the MTBM itself is minimal thus surging to the cutting tools is as well. Without a telecan, surge loads can cause excessive wear and even shock load damage to the cutting tools particularly in harder rock formations.

b. Pipe Failures – All pipe materials subjected to cam locking and/or wedging can fail. Clay pipe should not be used for rock microtunneling because of its low tensile strength. Steel casing is by far the most conservative selection.

In conclusion, during the past ten years rock microtunneling has become far more fact than fiction. With the advent of face access MTBMs, the benefits of the microtunneling method, such as slurry earth pressure balance, underwater retrievals, accuracy and the economy of one-pass pipe jacking, have been extended from soft ground and sedimentary rock conditions to full and mixed face hard abrasive rock conditions. The key is to know when, where, and how to use microtunneling in these challenging conditions.